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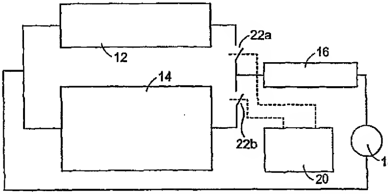
(54) Title: HYBRID BATTERY CONFIGURATION



(57) Abstract: A hybrid battery configuration supplies a load (16) having varying current requirements which may range from short periods of high current to extended periods of low to medium current. The hybrid battery configuration comprises a high rate, high power, energy storage device (12, 12a), a high energy battery (14), a current monitoring device (18), a microprocessor controller (20), and at least one switch (22a, 22b, 24a, 24b, 28). The high rate, high power energy storage device and the high energy battery are connected in parallel with each other, and in series with the load. The current monitoring device is connected in series with the parallel connected high rate, high power device and the high energy battery, and in series with the load. The switch is controlled by the microprocessor so as to switch at least one of the high power device and the high energy battery into and out of a series connection with the load.

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HYBRID BATTERY CONFIGURATION

FIELD OF THE INVENTION:

[0001] This invention relates to hybrid battery configurations, and particularly to configurations of hybrid batteries where the hybrid battery comprises a first, high rate, high power device – a capacitor or a supercapacitor, or a high power battery – and a second, high energy battery. Configurations in keeping with the present invention may employ a variety of batteries and energy storage devices having the same, similar, or disparate chemistries.

BACKGROUND OF THE INVENTION:

[0002] There is a long standing need to maximize battery performance for applications which require both high discharge rates and long run times. Invariably, attempts to maximize the configuration and characteristics of a single battery to satisfy all requirements, results in compromise. Neither the requirement for high discharge rate, particularly over a significant interval, nor long run times at low discharge rate, over a long interval in time, will be fully satisfied.

[0003] The high surface area interface which is required for low impedance, high rate systems is achieved in battery designs by a net reduction in the amount of active material. For example, recently developed organic electrolyte lithium ion and lithium polymer battery systems are designed with thin components that have exceptionally high surface area. This allows efficient discharge at higher rates.

[0004] However, notwithstanding that the energy content of the active materials is reasonably high, it still requires that the ampere hour capacity of such batteries be de-rated. On the other hand, the implementation of high surface area designs using low rate chemistries, results in thermal problems when such a battery system is used in high rate applications.

[0005] Moreover, of course, addition of active material to provide higher capacity will typically result in a slower acting system, with a relatively low ratio of surface area to active material mass, resulting in the inability of such battery systems to react quickly and to provide high rate discharge or charge.

[0006] A particular approach which is now being studied is to improve overall performance and to increase the safety of batteries that are used in high discharge rate applications, and to separate those functions of high current delivery and energy delivery. Particularly, a large, low impedance double layer capacitor, may be configured with a battery system in such a manner that the double layer capacitor can potentially supply large current spikes which pose problems to low discharge rate, high energy batteries.

[0007] A battery component of such a hybrid battery configuration, on the other hand, provides the energy for an extended operating range, particularly a long period of time at low discharge conditions. As well, as will be noted hereafter, the battery component of such a hybrid battery configuration provides the energy required to recharge the high rate capacitor, in some circumstances.

[0008] However, problems will arise when the total time of high current drain exceeds the capability of even the largest of capacitors. Thus, the solution of providing a hybrid battery system resolves that problem, by combining a high rate, high power device – typically a high rate battery, but possibly a capacitor or supercapacitor – together with a lower rate, high energy density design of battery.

[0009] The problem then becomes the management of the hybrid battery configuration so as to supply a load which has varying current requirements that range from short periods of high current to extended periods of low to medium current. As noted, that solution lies in the parallel provision, within a hybrid battery configuration, of a high rate, high power device – typically a high power battery, but possibly a high

power supercapacitor – together with a high energy battery, where the devices are connected in parallel.

[0010] Such a combination can provide enhanced performance in situations which require both high energy density and high power density. The parallel configuration enables the high power device to deliver high current on demand. This high rate, high power device must have low impedance, and it must always be available for discharge.

[0011] As will be noted hereafter, there is no requirement for the use of identical battery chemistries; however the high energy battery should be capable of recharging the high power device during "off" periods, or during periods of lower power delivery. Various configurations are contemplated, some using a DC to DC converter, others without such an element.

[0012] An optimal configuration is highly dependent on the application to which the hybrid battery is to be put. Some possibilities exist, such as:

A) The combination of a high energy density primary battery, with a secondary battery which is capable of higher rates of discharge.

B) The combination of a fuel cell together with a secondary battery which is capable of higher rates of discharge.

C) The combination of a high energy density secondary battery, together with a high power secondary battery of identical chemistry.

D) The combination of a high energy density secondary battery, together with a high power secondary battery of different chemistry.

[0013] In each instance, of course, the two batteries, or high power device and battery, or fuel cell and battery, are configured in parallel one to the other as a hybrid battery, which in turn is in series with its load. Quite often, the high rate battery is designed with a low active material loading, so that it must be periodically recharged by the high energy battery.

[0014] Indeed, all of the types of possible configurations which are noted above may operate solely with the high power battery in the circuit, if the ampere hour capacity of the high power battery is sufficient to sustain the load over an operating cycle such that the battery may be recharged during the "off" period of the operating cycle. In such situation, then, the high power battery provides the power for the load, over the complete duty cycle, without load sharing between the two power sources.

[0015] More likely is the situation where the duty cycle is comprised of extended periods of low to medium rate discharges, interspersed with shorter periods of high rate discharges. In those situations, where the periods of high rate discharge are longer than would normally be supported even by a supercapacitor, such high rate discharges may be supported by a high power battery, and the low rate discharges may be supported by the high energy battery.

[0016] In such circumstance, the high power battery is recharged by the high energy battery during periods of low current drain. Moreover, during discharge, the high power battery and the high energy battery can be switched into and out of the circuit.

[0017] For example, the high energy battery can be switched out during high current pulses, and the high power device can be switched out during extended periods of low current drain so as to provide a time dependent load sharing. Of course, such a scheme requires current monitoring and microprocessor control.

[0018] Alternatively, both batteries may operate in a parallel configuration. In that case, during periods of high current delivery the voltage of the parallel combination of the high power battery and the high energy battery, will become depressed. The proportion of current drawn from each battery will then be dependant on the relative state of charge of the batteries, and the impedance difference between the batteries, as well as the duration and magnitude of the current pulse.

[0019] Medium rate, short duration pulses may be supported by the discharge of the double layer capacity of a high power battery. Higher current pulses would depress the voltage levels into the Faradaic operational region of the high power unit, so that long term high current pulses can be sustained. It follows that removal of a low impedance load will allow charge to be predominately transferred from the high energy battery.

[0020] The load current level above which the current is predominately supported by the high powered battery is a design parameter which is dictated by the application, and determined by the discharge characteristics of the two batteries in the system. The transition can be modified by adjustment of the number of unit cells in each battery, by variation of battery chemistries, and by the individual mechanical and chemical design of the respective batteries.

[0021] Of course, it is also possible to actively control the proportion of current being delivered by each battery in a parallel hybrid battery configuration, by the use of FETs in one or more legs of the parallel string.

DESCRIPTION OF THE PRIOR ART:

[0022] United States patent 6049141, issued April 11, 2000 to Sieminski at *et al*, teaches a device and a method for allowing multiple batteries to share a common load. In this case, however, the discussion of load sharing is directed to the control of two parallel batteries without any recharge process which would be necessary for extremely high rate units that are designed with low active material loading. In other words, there is no recharge capability within the parallel battery system contemplated in this patent; and the only charge capability is by the use of an external charger in respect of any battery in the battery system.

[0023] In contradistinction, the present invention provides for recharging of a high power device—typically, a high power battery but possibly a high rate, high power

capacitor – by delivering energy to it from the high energy battery with which it is in parallel.

SUMMARY OF THE INVENTION:

[0024] In accordance with one aspect of the present invention, there is provided a hybrid battery configuration for supplying a load having varying current requirements which range from short periods of high current to extended periods of low to medium current. The hybrid battery configuration comprises a first, high rate, high power, energy storage device; a high energy battery; a current monitoring device; a microprocessor controller; and at least one switch device.

[0025] The high rate, high power energy storage device and the high energy battery are connected in parallel with each other, and in series with a load.

[0026] The current monitoring device is connected in series with the parallel connected high rate, high power device and high energy battery, and in series with the load.

[0027] The switch means is controlled by the microprocessor so as to switch at least one of the high power device and the high energy battery into and out of a series connection with the load.

[0028] One prevision of the present invention is that the high rate, high power energy storage device is a high rate, high power capacitor. If so, the at least one switch may be connected to the high rate, high power capacitor, so as to take it into and out of a series connection with the load.

[0029] Typically, in any configuration of hybrid battery in keeping with the present invention, the at least one switch may be a Field Effect Transistor (FET).

[0030] In most configurations of hybrid battery in keeping with the present invention, the high rate, high power energy storage device is a high power battery. If so, then typically such a hybrid battery configuration may also comprise a DC to DC

converter in series connection between the high power battery and the high energy battery.

[0031] Here, the switch device is arranged so as to connect the high power battery and the high energy battery directly to each other when in a first switch position, and to connect the high power battery and the high energy battery to each other through the DC to DC converter when in a second switch position.

[0032] The present invention contemplates that the microprocessor controller may be adapted to control a recharge operation of the high rate, high power energy storage device from the high energy battery. If so, this recharge operation will be in keeping with predetermined criteria for the state of charge of the high rate, high power energy storage device, and the level of current being drawn by the load.

[0033] The present invention contemplates that the high rate, high power energy storage device may be chosen from the group which consists of capacitors and supercapacitors, thin film lead acid batteries, thin plate lead acid batteries, thin film nickel zinc batteries, thin film silver zinc batteries, thin film lithium ion batteries, and high rate nickel oxide alkaline batteries.

[0034] Likewise, the present invention contemplates that the high energy battery may be chosen from the group which consists of high energy density primary batteries, fuel cells, and high energy density secondary batteries.

[0035] Still further, the high energy density secondary battery may be one which is chosen from the group consisting of high energy lithium ion batteries, high energy lead acid batteries, high energy lithium polymer batteries, high energy nickel zinc batteries, and high energy nickel metal hydroxide batteries.

[0036] If there is a Field Effect Transistor associated with each of the high rate, high power energy storage device and the high energy battery, and each of the FETs is under the control of the microprocessor, then load sharing delivery of energy to the load is controlled, in keeping with predetermined criteria of current flow requirements by

the load, and in keeping with predetermined criteria concerning state of charge of each of the high rate, high power energy storage device and the high energy battery.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0037] The novel features which are believed to be characteristic of the present invention, as to its structure, organization, use and method of operation, together with further objectives and advantages thereof, will be better understood from the following drawings in which a presently preferred embodiment of the invention will now be illustrated by way of example. It is expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention. Embodiments of this invention will now be described by way of example in association with the accompanying drawings in which:

[0038] **Figure 1** is a simple schematic of a battery configuration for hybrid batteries in keeping with the present invention;

[0039] **Figure 2** is similar to Figure 1, showing utilisation of different switch elements;

[0040] **Figure 3** shows a further configuration where a DC to DC converter is connected between the batteries of the hybrid battery configuration.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS:

[0041] The novel features which are believed to be characteristic of the present invention, as to its structure, organization, use and method of operation, together with further objectives and advantages thereof, will be better understood from the following discussion.

[0042] Referring first to Figures 1 and 2, simplified configurations are illustrated for a hybrid battery. In each of those Figures, a high rate, high power device 12 is shown connected in parallel to a high energy battery 14. That parallel connection

is connected in series with a load 16, which is also in series with a current monitoring device – an ammeter – shown at 18.

[0043] A microprocessor controller 20 is shown, and it will typically be connected to the devices 12 and 14, and the ammeter 18, in manners well known to persons skilled in the art.

[0044] Also, the microprocessor controller 20 is connected to switches 22, one or either of which will be present in the circuit, if not both, as described hereafter.

[0045] In Figure 2, the switches 22 are replaced by FETs 24.

[0046] A similar configuration is shown in Figure 3. However, in this case, it is seen that a DC to DC converter 26 is provided, and its connection between the high rate, high powered battery 12 a is dependent on the switch position of switch 28.

[0047] Typically, switch 28 is a solid state switching device, but for purposes of simplicity it is shown as being a double throw, single pole – or two-position – switch.

[0048] In a configuration in such as that shown in Figure 1, in some circumstances if the load 16 requires a very high current, the microprocessor controller 20, in association with the current monitoring device 18, may open the bottom switch 22b, so that a high current pulse is provided to the load from the high rate, high power device 12.

[0049] In other circumstances, if the load is a very low rate load, the switch 22b will be closed, and switch 22a will be opened.

[0050] Moreover, in some circumstances if the energy storage of the device 12 has been depleted to some extent, such that its terminal voltage has reduced, then switch 22a may be closed, or cycled from an open to a closed position by the microprocessor 20, so as to recharge the high rate, high power device – a capacitor or battery – from the high energy battery 14.

[0051] In the circuit shown in Figure 2, the same functions may be followed.

[0052] Moreover, because of the presence of the FETs 24a and 24b, it is evident that load sharing under the control of microprocessor controller 20 can be effected, in the manner well known to those skilled in the art.

[0053] Similarly, in a circuit such as that shown in Figure 3, a decision may be made by the microprocessor controller to connect the high rate, high power battery 12a in parallel with the high energy battery 14 by placing the switch 28 in its first position. Then, a simple parallel connection is made between the batteries. Of course, FETs may be placed in the parallel legs, in the same manner as shown in Figure 2.

[0054] Moreover, in the event that a decision is made for the high rate, high power battery 12a to be recharged from the high energy battery 14, through the DC to DC converter 26 – which is typically a pulse output device adapted for high rate charging of the battery 12a – then the switch 28 is placed into its second position.

[0055] Indeed, any operation of any of the switches and FETs, as described above, may be essentially instantaneous, and for very short periods of time, depending on the load characteristics and demands as required by the load 16, and as sensed using the current monitoring device 18 together with the microprocessor controller 20.

[0056] Thus, as noted, the microprocessor controller 20 may reach a decision to control the recharge operation of the high rate, high power energy storage device 12 or 12a from the high energy battery 14, in keeping with predetermined criteria for this state of charge of that device 12 or 12a, and the level of current being drawn by the load 16.

[0057] While the device 12 or 12a may be a supercapacitor, it is more likely to be a thin film lead acid battery, a thin plate lead acid battery, a thin film nickel zinc battery, a thin film silver zinc battery, a thin film lithium ion battery, or a high rate nickel oxide alkaline battery.

[0058] A high energy battery 14 may be a fuel cell, it may be a high energy density primary battery; or more likely, it is a high energy density secondary battery.

[0059] If so, typical high energy density secondary batteries which may be employed in keeping with the present invention include high energy lithium ion batteries, high energy lithium polymer batteries, high energy nickel zinc batteries, and high energy nickel metal hydroxide batteries.

[0060] Finally, it has been noted that load sharing between the devices 12 or 12a, and 14, is through the FETs 24, under the control of the microprocessor controller 20 in keeping with predetermined criteria of current flow requirements by the load 16 and the state of charge of each of the high rate, high power energy storage device 12 or 12a and the high energy battery 14.

[0061] There has been described a hybrid battery configuration for supplying a load, where typically the load has varying current requirements which may range from short periods of high current to extended periods to low to medium current. Alternative configurations have been described with respect to the manner in which current and energy flow from the batteries to the load, or from the high energy battery to the high power device, may be effected. An alternative arrangement providing for specific recharging of a high rate, high power battery from the high energy battery, using a DC to DC converter—and thereby independent of any external battery charger requirements -- has also been described.

WHAT IS CLAIMED IS:

1. A hybrid battery configuration for supplying a load (16) having varying current requirements ranging from short periods of high current to extended periods of low to medium current, said hybrid battery configuration comprising:

a high rate, high power, energy storage device (12, 12a);

a high energy battery (14);

c h a r a c t e r i z e d by further comprising:

a current monitoring device (18);

a microprocessor controller (20); and

at least one switch device (22a, 22b, 24a, 24b, 28);

wherein said high rate, high power energy storage device and said high energy battery are connected in parallel with each other and in series with a load;

wherein said current monitoring device is connected in series with said parallel connected high rate, high power device and said high energy battery, and in series with said load; and

wherein said switch means is controlled by said microprocessor so as to switch at least one of said high power device and said high energy battery into and out of a series connection with said load.

2. The hybrid battery configuration of claim 1, wherein said high rate, high power energy storage device is a high rate, high power capacitor, and said at least one switch is connected thereto, so as to take said high rate, high power capacitor into and out of a series connection with said load.

3. The hybrid battery configuration of claim 1, wherein said at least one switch is a Field Effect Transistor.

4. The hybrid battery configuration of claim 1, wherein said high rate, high power energy storage is a high power battery.

5. The hybrid battery configuration of claim 4, further comprising a DC to DC converter (26) in series connection between said high power battery and said high energy battery; and

wherein said switch device (28) is arranged so as to connect said high power battery and said high energy battery directly to each other when in a first switch position, and to connect said high power battery and said high energy battery to each other through said DC to DC converter when in a second switch position.

6. The hybrid battery configuration of claim 1, wherein said microprocessor controller is adapted to control a recharge operation of said high rate, high power energy storage device from said high energy battery, in keeping with predetermined criteria for the state of charge of said high rate, high power energy storage device, and the level of current being drawn by said load.

7. The hybrid battery configuration of claim 1, wherein said high rate, high power energy storage device is chosen from the group consisting of capacitors and supercapacitors, thin film lead acid batteries, thin plate lead acid batteries, thin film nickel zinc batteries, thin film silver zinc batteries, thin film lithium ion batteries, and high rate nickel oxide alkaline batteries; and

wherein said high energy battery is chosen from the group consisting of high energy density primary batteries, fuel cells, and high energy density secondary batteries.

8. The hybrid battery configuration of claim 6, wherein a high energy density secondary battery is chosen from the group consisting of high energy lithium ion batteries, high energy lead acid batteries, high energy lithium polymer batteries, high energy nickel zinc batteries, and high energy nickel metal hydroxide batteries.

9. The hybrid battery configuration of claim 3, wherein a Field Effect Transistor is associated with each of said high rate, high power energy storage devices and said high energy battery, and each of said FETs is under the control of said microprocessor so as to control load sharing delivery of energy to said load in keeping with predetermined criteria of current flow requirements by said load and the state of charge of each of said high rate, high power energy storage device and said high energy battery.

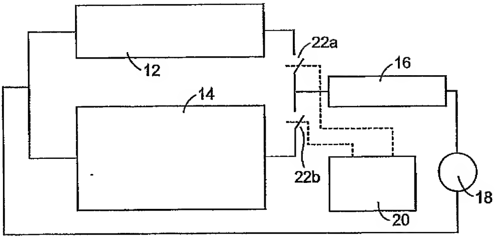

Figure 1

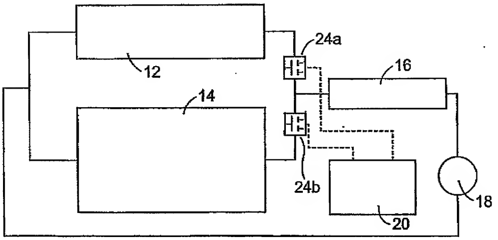

Figure 2

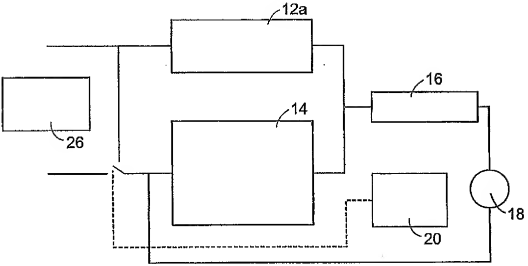

Figure 3